US Army Corps
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Overview of Regional Coastal Sediment Processes and Controls

PURPOSE

The Coastal and Hydraulics Engineering Technical Note (CHETN) herein summarizes selected regional coastal sediment processes that may influence the design, operation, and maintenance of engineering projects. Various regional mechanisms that significantly control or restrict coastal and inlet sediment transport are discussed. Examples are given from different U.S. coasts where regional processes and controls determine the sediment transport pattern, associated shoreline evolution, and navigation channel performance.

BACKGROUND

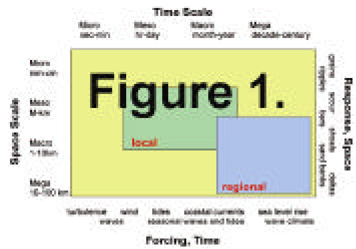
The U.S. Army Corps of Engineers has the mission to ensure navigability of Federal waterways. Congress authorized this mission in 1824, when the Corps was directed to remove sandbars and snags from major navigable rivers. Today, the Corps' navigation program involves the planning, design, construction, operation, and maintenance of riverine, estuarine, and coastal waterways to meet navigation needs. Inlet channels and entrances are major elements of the sediment-exchange system of the surrounding landforms that include the mainland, wetlands, bay beaches, and ocean beaches. Inlet navigation projects, typically including jetties, channel maintenance dredging, and disposal of dredged material, are a major element of the coastal sediment budget. Although sand bypassing has been implemented at individual inlet navigation projects, only a limited area within or around project dimensions was typically analyzed. Records of shoreline change indicate that both natural and improved inlets alter longshore sediment transport patterns and the shoreline position far beyond an inlet (e.g., Dean 1987; Bruun 1995), making it necessary to analyze shoreline response at a larger spatial scale than what is commonly done in individual projects. The need for project design and management decisions for longer time periods is increasing, also emphasizing the need to consider larger spatial areas in inlet navigation projects.

Many inlet navigation projects have been in place for more than a century, and their ranges of influence far exceed local project dimensions. Similarly, sand from periodically nourished beaches likewise will travel far beyond project limits. The time and space scales of major coastal projects therefore call for regional considerations to address the full consequences and interactions of engineering activities as well as the wide-scale influence of natural processes and features. This technical note describes selected regional coastal sediment processes and controls that are typically not addressed in the design, operation, and maintenance of coastal projects. Here, a control represents a mechanism that imposes constraints on the sediment transport, in mathematical terms dictating or influencing boundary conditions on the governing processes. The coastal processes and controls are primarily discussed in the context of longshore sediment transport and shoreline evolution at the regional scale.

TIME AND SPACE SCALES OF COASTAL SEDIMENT PROCESSES

Coastal sediment processes are commonly classified by their characteristic scales of the forcing and responses. At present, mainly the local scale is employed in project design, whereas the need for considering larger area and longer time implies including regional processes and controls. Several systems have been proposed that identify and define a number of scales employed in such classification. Here, only one scale besides the regional scale is discussed, namely the local scale. The local scale refers to the scale at which coastal processes are typically considered in engineering design at present, corresponding to time periods of 0.01-30 years and spatial areas of 0.1-10 km. In contrast, the regional scale is taken to include coastal processes operating at time scales of 10-250 years and space scales on the order of 1-100 km.

Figure 1 illustrates how the local and regional scales fit into the context of forcing and response for coastal processes in a wider scale spectrum. Sediment transport is generated by mechanisms ranging from turbulence at a fraction of a wave period to sea level rise varying over centuries. Different sedimentological and morphological features are associated with this transport and its gradients, covering scales from ripples to barrier island



chains. In engineering projects, the design life of the structure or activity will in great part define the necessary scale of interest and the processes to consider.

REGIONAL PROCESSES

A sediment budget balances sources and sinks of sediment together with the resultant morphology change for a particular area and time period. Such budgets are often formulated at a regional scale (Rosati and Kraus 1999), but the dynamics of the processes underlying the transport gradients responsible for the sources and sinks is not resolved in a classical sediment budget approach. Here, several different transport processes at the regional scale that contribute to navigation channel performance and shoreline evolution, as well as the response of the entire beach in the nearshore, are discussed. These processes are associated with sources and sinks as in a sediment budget, but the objective is to explain and exemplify the dynamics in terms of process forcing and response.

Longshore Sand Transport

Waves approaching obliquely to the coast generate a longshore current that transports sediment along the shore. Tidal and wind-generated currents also contribute to this sediment transport, although it is the stirring by the breaking waves that mobilizes the sediment transported by longshore (and cross-shore) currents. Gradients in the longshore transport rate alter the shoreline, resulting in areas of erosion and accretion. The gradients and their characteristic scale determine the spatial extent of these areas. Figure 2 displays an example of gradients in longshore transport, illustrating where areas of accretion and erosion occur. In this particular case, the regional net transport is directed toward the right, but local variations in the breaking are superimposed on the regional trend, generating the local areas of erosion and accretion. A divergence point for the local transport creates an erosional area and a convergence point an accretionary area. The mechanism causing the gradients in local transport may be related to, for example, structures, engineering activities, and the offshore bathymetry. Similarly, gradients in the regional transport may produce areas of accretion and erosion, leading to complex regional shoreline shapes upon which the local shoreline responds to transport gradients.

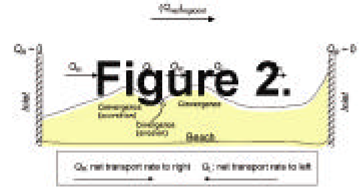


Figure 2.

Various types of controls can establish spatial gradients in the longshore sediment transport rate at the regional scale as, for example, offshore contours, shadowing by large landmasses, and geological constraints such as headlands. Under certain conditions, equilibrium may be attained, eliminating the gradients at the regional scale and leading to shoreline trends that are stable over longer time, such as indicated in Figure 3.

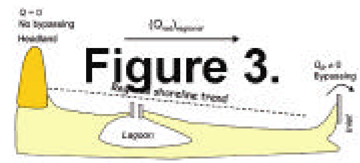
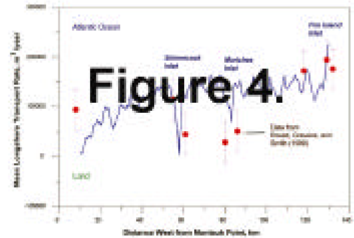


Figure 3.

Wide-area wave generation and propagation is another factor that may produce regional gradients in the longshore transport. Depending on fetch properties, characteristics of weather patterns, shelf topography, etc., wave conditions can vary alongshore and give rise to regional transport gradients. As an example of the variation in longshore sediment transport rate at the regional scale, the calculated mean annual rate along the south shore of Long Island, NY (from Montauk Point to Fire Island Inlet) is shown in Figure 4 (Larson, Hanson, and Kraus 2002; also, see discussion in example section of this technical note). In the calculation, hindcast wave data from three Wave Information Studies (WIS) stations (sta 75, 78, and 81; see *http://bigfoot.wes.army.mil/w002.html*) were employed. Bypassing and sand storage at inlets were simulated using the reservoir model by Kraus (2000a). A clear regional trend in the transport pattern is evident from Figure 4, showing an increase in the transport rate going west (to the right in the figure).



The alongshore coordinate in the figure starts at Montauk Point, which constitutes the eastern end of Long Island, where little sediment enters the system. This restriction in sediment input together with shadowing by the continental United States and Long Island itself of waves from the northeast cause the regional trend in the longshore transport with increase in the net rate directed toward the west. Significant local variations in the transport rate are superimposed on this trend, especially around the inlets where large amounts of sediment are stored in the shoals. In Figure 4, the calculated transport rates are also compared with a previous sediment budget to derive the net rate at certain locations (Rosati, Gravens, and Smith 1999). The best estimate of the mean annual transport rate is given at selected locations (thick dot) together with an interval indicating the probable variation in the rate (vertical bar).

Cross-shore Sand Transport

Net cross-shore exchange of sediment may occur over long time periods and large areas, having implications for the regional shoreline evolution. During a typical year, the cross-shore net transport at the boundaries of the nearshore zone may be small, especially at the seaward end, but over decades or centuries the net contribution could be significant. Also, in the case of extreme events large net transport could take place over a short time period, having implications for the evolution of the nearshore topography at much longer time scales than the storm itself. Onshore transport from the shelf area to the nearshore has been reported at several places, for example, the outer banks of North Carolina (Pierce 1969) and Long Island (Schwab et al. 1999; Williams and Meisburger 1999), although the contribution from this transport to the overall sediment budget in the nearshore is difficult to estimate (Rosati, Gravens, and Smith 1999).

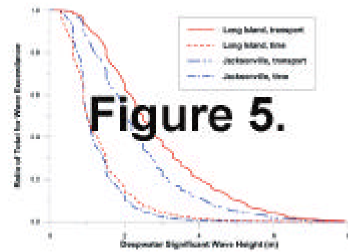
However, there are also places where sediment might be lost from the nearshore to the shelf area, for example, to submarine canyons along the coast of California (Shepard 1967). The long-term net sediment exchange between the nearshore and the shelf area is probably related to the general properties of the shelf, such as width, slope, and sediment availability. In turn, this implies that the tectonic history and characteristics of the coast, acting as controls for regional processes, influence the cross-shore material exchange. Inman and Nordstrom (1971) demonstrated that the large-scale characteristics of coastlines show a high degree of correlation with known tectonic features (see discussion on tectonic environment in the following paragraphs).

Relative change in sea level causes cross-shore exchange of sediment that occurs over long time periods because of the time scale of the forcing. At present, as a global average, the sea level is rising about 1 mm/year (Gornitz and Lebedeff 1987; Gornitz 1995), although there are significant variations depending on geological and climatological conditions. A general increase in the rate is expected during the coming centuries due to global warming. Sea level rise causes sediment to be transported offshore as the beach profile adapts to the new equilibrium situation. The Bruun rule is often employed to estimate the shoreline retreat due to sea level rise (Bruun 1962), where the equilibrium profile for the beach is shifted shoreward until eroded and deposited volumes agree.

Transport During Storms

Although the time scale (days) of storms is shorter than the regional scale, storms can still play a role in regional coastal processes and modify both local and regional shoreline evolution. Storms are of short duration, but the magnitude of sand transported during annual storms can be comparable to the total transport that occurs during the rest of the year under nonstorm wave conditions. Storms also cause cross-shore transport that can shift the beach away from its normal (near-equilibrium) state, and the gradual return to the original state or to a different equilibrium state could occur at time scales corresponding to regional processes (Larson and Kraus 1994). The equilibrium state of the beach can be represented by shoreline configuration, the beach profile shape, or the properties of different morphological features (e.g., ebb shoal, bypassing bar, spit formation).

Figure 5 illustrates how much of the longshore transport that is associated with large waves (i.e., storms) for two sites in the United States, namely Long Island, NY, and Jacksonville, FL. The calculations were based on WIS information and the Coastal Engineering Research Center (CERC) formula using a representative shoreline orientation. In the figure, the ratio of the total gross longshore sediment transport rate calculated for waves above a certain height is plotted as a function of the height. Also, the normalized duration a specific wave height is exceeded is given with respect to the height. For Long Island, waves with heights greater than 4 m are estimated to contribute to about 20 percent of the total gross transport, although they occur less than 2 percent of the year. Similarly, for Jacksonville, about 20 percent of the gross transport is generated by the 2 percent highest waves.



Barrier islands exposed to severe storms could suffer other long-duration consequences related to the cross-shore exchange of material. During storm surge, waves may overtop the island, and overwash[1] of sediment occurs. This sediment is deposited on the back of the island and is lost from the nearshore system or transported back at a slow rate by wind. Overwash can also

[1] A mass of water representing the part of the uprush that runs over the berm crest (or other structure) and does not flow directly back to the sea or lake.

lead to breaching of the barrier island and the creation of an inlet. The inlet may stay open or close due to the longshore transport, but any sediment accumulation in flood and ebb shoals will change the large-scale sediment transport pattern and cause shoreline responses at the regional scale. Figures 6 and 7 illustrate the washover fans[2] along a barrier island created during major storms. Figure 6 shows the offset in shoreline location at the inlet because of the interruption of the longshore transport rate, where the shoreline retreat downdrift the inlet occurs over the regional scale.

[2] Material deposited by the action of overwash; specifically, a small delta-shaped feature built on the landward side of a barrier beach, separating a lagoon from the open sea, produced by storm waves breaking over low parts of the barrier and depositing sediment in the lagoon.

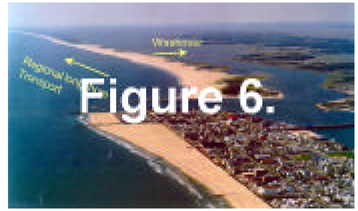


Figure 6.

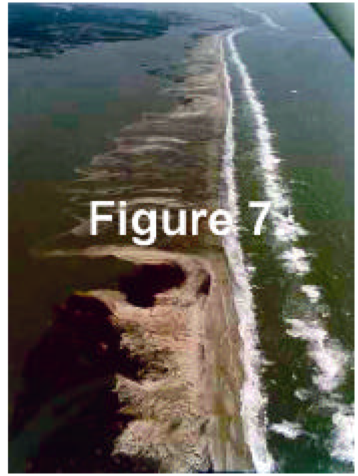


Figure 7

Wind-Blown Sand Transport

On beaches where a strong seasonal wind blows, sand transport by wind can be a significant mechanism contributing to the total transport rate and associated beach change (Sherman et al. 1996). The temporal and spatial patterns in the wind field controlling this sand transport often have characteristic scales that are within the regional range. For example, buildup of the dunes after storm erosion through wind-blown sand may take decades before full recovery has taken place (Mathewson 1987). Also, progression of coastal dunes and initiation of new dune lines are phenomena that occur at the regional time scale

(Pethick 1984). The *Shore Protection Manual* (1984) documents typically observed rates of wind-blown sand in the range 2.5 to 25 m^3/m/year, which implies that the wind can give a substantial contribution to the sediment budget over large areas and long time periods. Hull and Taylor (1999) demonstrated that the sand transport by wind had to be taken into account in establishing a sediment budget for Ponce De Leon Inlet in Florida. Long-term sand transport rates were estimated with the formula of Hsu (1974) together with wind statistics. The wind may also influence the sand transport in the surf zone by inducing nearshore currents that interact with wave- and tide-generated currents.

Cliff and Dune Erosion

Cliff coasts (or rocky coasts) may experience erosion by continuous wave attack (or during extreme events) supplying the nearshore area with material. Some of this material is coarse enough to be deposited and transported in the coastal zone, whereas finer grain sizes disappear offshore. The rate of cliff erosion is typically small depending on the strength of the cliff, but over a longer time period the retreat and associated input of material might be substantial. Sunamura (1992) summarized worldwide coastal cliff erosion rates, where the maximum rates may amount to several meters per year. On the Outer Cape Cod, MA, cliffs consisting of glacial deposits have been receding up to more than 2 m/year, whereas cliffs of similar material have been eroding even more in the Great Lakes (in some locations up to 4 m/year). A portion of the eroded material is deposited in the surf zone, where currents and waves transport it further along the coast. Figure 8 shows cliffs at Torrey Pines, CA, which exceed 90 m in height and consist of Eocene sandstone and shale. Moore, Benumof, and Griggs (1999) determined that, from 1952 to 1994, the erosion rates in this area ranged from 2 to 55 cm/year with an average of 18 cm/year. The dominant erosive mechanism is due to landslides and subsequent erosion by waves (Personal Communication, Kiki Runyan, January 2002, doctoral candidate, University of California at Santa Cruz).

Dune erosion adds sediment to the nearshore zone at the regional scale in a manner similar to cliff erosion; however, it normally occurs more episodically in connection with severe storms. The sudden material input from dune erosion may disturb the equilibrium conditions and force the shoreline or profile to a state from which it returns slowly back to equilibrium. These extreme events could supply substantial amounts of sediment to the nearshore that are important to account for at the regional level. Savage and Birkemeier (1987) summarized measurements of the impact of severe storms on the U.S. Atlantic Coast in terms of shoreline change and eroded volume. The median eroded volume above National Geodetic Vertical Datum (NGVD) for 46 events were 10 m^3/m, with a maximum value of 31.4 m^3/m alongshore recorded at Westhampton Beach (18 March 1973). However, the scatter in the data points from each site was considerable for a particular event, where individual values could reach up to 150 m^3/m of erosion or even display accretion. The amount of erosion during a storm is mainly a function of peak water level, wave conditions, subaerial profile geometry, and sediment grain size or fall speed.

Sediment Supply from Rivers

Although rivers worldwide bring significant amounts of sediment to the coast, only a small percentage of the transported material is coarse enough to be deposited in the nearshore. The finer fractions, which typically dominate, move offshore into deeper water before they come to rest. It is often the smaller rivers that contribute relatively the most to the littoral sediment transport. For example, the sediment load brought into the Gulf of Mexico by the Mississippi River contains only 2 percent sand, whereas the rest is clay and silt. Sand-sized sediment is not supplied to the coasts by rivers on most segments of the U.S. Atlantic and Gulf coasts, but in southern California several minor rivers make a significant contribution to the local sediment budget (*Shore Protection Manual* 1984). The sediment yield increases with the relief of the drainage basin and with decrease in basin size, which explains the importance of river sediment transport in California (Inman and Jenkins 1999). Other factors that determine the sediment load are climate, rainfall, and geological conditions.

The sediment transport from rivers typically exhibits variations on the seasonal scale, but long-term fluctuations over decades have also occurred (Inman and Jenkins 1999). These fluctuations in transport rate on the regional time scale are related to the climatic conditions, where El Nino/Southern Oscillation-induced changes may be significant. The U.S. Geological Survey maintains a database of measurements of flow and suspended sediment concentrations carried out in a large number of rivers in the United States, including many measurement locations in the vicinity of the coast (*http://water.usgs.gov*). These data can be consulted for obtaining estimates of the contribution from river sediment transport to the evolution of the shoreline. In arriving at such estimates, the portion of river sediment trapped in the nearshore needs to be assigned.

Sediment Losses to Submarine Canyons

Cross-shore exchange of material may involve loss of sediment to the offshore, especially at the longer time scale over which processes active on larger spatial scales become important and the sediment exchange include topographic areas in deeper water that may trap sediment. Submarine canyons are a prominent example of such traps that may permanently store sediment, removing it from the coastal system. Limited information is available on how the sediment transport to the submarine canyons occurs (time and space), as well as the relative influence of the canyons on the nearshore sediment budget. Fine material discharged from rivers that is not deposited in the nearshore zone often deposits in submarine canyons, if canyons are present and a part of the coastal transport system. However, the supply of river sediment to the canyons may be intermittent and mainly associated with large flood events in the river (Mullenbach and Nittrouer 2000).

Offshore of the continental United States, most submarine canyons are found along the California coast (Shepard 1967), although there are other locations where such canyons occur (e.g., Hudson Canyon off the New York coast). Some sediment budget studies for littoral cells in California have made attempts to include the canyons and to quantify the sediment losses associated with these topographic features (Herron and Harris 1966).

REGIONAL CONTROLS

This section contains information on several leading regional factors that may influence coastal change and navigation channel performance.

Offshore Contours

Waves approaching the shoreline are transformed by the bottom topography through the processes of shoaling, refraction, diffraction, reflection, and breaking. The topography controls the properties at breaking, which in turn mainly determines longshore sediment transport rates and associated shoreline evolution. Offshore topography exhibits variations at many scales, including the local and regional scale, and these will modify the alongshore pattern of wave breaking. Large-scale trends in the offshore contours influence the shoreline evolution so that complex shapes could be maintained and represent equilibrium states. On many coasts there is a feedback from the shoreline and associated profile movement on the offshore contours, leading to a complex interaction between waves and bottom topography. However, large-scale variations in the offshore contours, controlling regional shoreline evolution (and, indirectly, altering local shoreline response), may be stable over long time periods and display little influence from the shoreline movement.

Shadowing

The large-scale geometry of the coast could be such that wave generation and propagation are modified from those in deep water. Shoreline stretches may be sheltered from waves coming out of certain directions having significant effects on the net longshore sediment transport and associated transport gradients. Thus, focusing only on the local coastal geometry could introduce substantial errors in deriving a wave climate for transport calculations. One classical example of shadowing from landmasses and the effects on the transport pattern is the New Jersey coast (Kraus, Gravens, and Mark 1988). Along the northern part of the New Jersey coast, the shadowing from Long Island produces a net northerly transport at the most northern portion, and a net southerly transport further south. The nodal point (i.e., where the net transport is zero as a long-term average) is located near Mantoloking, located about 75 km south of Sandy Hook, NJ (Caldwell 1966; see Figure 14).

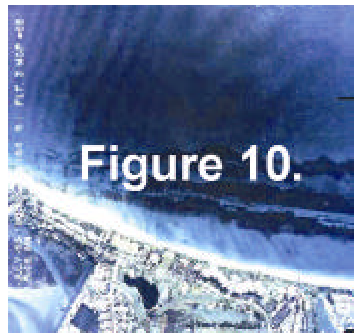
Rhythmic Features

Morphological features at many characteristic scales appear in the nearshore, ranging from ripples to large-scale longshore sand waves. At the upper end of this scale spectrum, features appear that evolve at the regional scale, having spatial wavelengths on the order of kilometers and existing over decades to centuries (Verhagen 1989; Thevenot and Kraus 1995; Gravens 1999). Typical amplitudes of these sand waves are 10-50 m for the ones responding at the decadal scale and 100-500 m for the ones changing over centuries. The sand waves can be stationary or move alongshore, but their amplitude typically varies with time. Propagation and amplitude variation induce changes that may cause consequences for shoreline evolution and channel infilling. In principle, if the governing mechanisms for sand wave formation and propagation were known, the process as such could be described and quantified. However, these mechanisms are still not sufficiently understood, and sand waves may instead be treated as a control acting to modify the shoreline configuration. Longshore sand waves are readily identified through sequential aerial (preferably vertical) photography.

Figure 9 illustrates longshore sand waves occurring along Southampton Beach on the southern shore of Long Island. Thevenot and Kraus (1995) identified 11 sand waves along this stretch of coast, implying one sand wave per 1.5-m shoreline. The waves were observed to migrate south at typical speeds of 0.5-1.5 km/year, with greater speeds occurring in the winter. This speed is somewhat greater than the migration speed Verhagen (1989) determined for the larger sand waves appearing along the Dutch coast, where the waves moved 100-300 m/year. Sonu (1968) postulated that the longshore speed of sand bodies should approximately vary inversely with the wavelength of the body, which was confirmed by Thevenot and Kraus (1995).

Hard Bottom

A hard bottom (HB) is a nonerodible bottom feature that may be located anywhere on the subaerial and subaqueous beach. HB is encountered in a wide range of environments from the coral reefs in the South Pacific to cohesive shores in the Great Lakes. Various forms and types of HB are commonly encountered along north-central Atlantic Ocean coast of Florida, and they might have spatial extensions that restrict transport of sediments at the regional scale. HB consists of natural materials such as worm rock, limestone, coquina, coral reefs, sedimentary rocks, as well as artificial structures such as dumped concrete and rubble. Figure 10 is an aerial photograph showing exposed HB in the clear nearshore water off Martin County Beach Park, at Bathtub Reef, FL. The HB appears as at least three linear strips oriented approximately with the trend of the shoreline (HB is dark). It is expected that the narrow sand strips lying between the HB plateaus are only veneers of sand



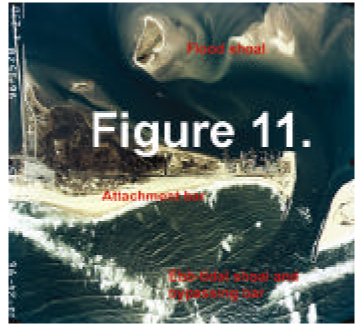
temporarily trapped between them. Qualitative observation indicates that sand moves on and off such HB areas according to the prevailing wave conditions. HB will restrict sand movement because the area it occupies does not contribute to the sediment budget (e.g., Foster and Savage 1989).

Geological Setting

The geological setting controls coastal processes to a large degree (Riggs, Cleary, and Snyder 1995), especially at the regional level where the scale is closer to geological processes than what the local scale is. Coastal geology encompasses both the geomorphology (the shape) of the landforms and the nature of the ancient strata that underlie our outcrop in the region (HQUSACE 1995). Knowledge of the geology is needed not only for understanding the controls acting on the coastal processes, but also for characterizing the processes themselves. For example, cliff erosion or the transport of material to submarine canyons depend on the underlying geology. Also, the material being transported is a function of the geological properties of the area, which conditions most regional coastal processes.

Inlets

Inlet flood- and ebb-tidal shoals store sand transported by longshore and tidal currents, and they also transfer or bypass sand to the downdrift beach according to factors such as the shoal properties, wave conditions, and magnitude of the tidal prism. The time scales of shoal growth towards an equilibrium state and associated increase in the bypassing transport rate may be in the range of decades to centuries. Thus, at the regional scale inlets could have large impact on the shoreline evolution in space and time, although they are of limited spatial extent themselves. Kraus (2000a) developed an analytical model of the ebb-shoal complex based on a conceptualization of the inlet into the following morphological elements: ebb-tidal shoal, flood-tidal shoal, bypassing bar, and attachment bar. Figure 11 shows Shinnecock Inlet on Long Island, NY, that displays the locations of these different elements (note that the wave breaking indicates where the shoals occur). By means of sediment volume conservation equations and equations to transfer sediment between the morphological units, Militello and Kraus (2001) predicted the time evolution of the shoals and the bypassing transport over a calculation interval covering 250 years. Comparison with field data from Ocean City and Shinnecock Inlet (Kraus 2000b) confirmed the role of inlets on the regional sediment transport pattern, which in turn determined in part shoreline evolution along Assateague Island, MD.



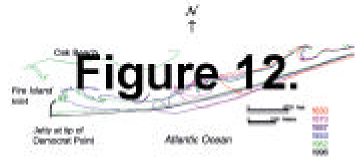
Tectonic Environment

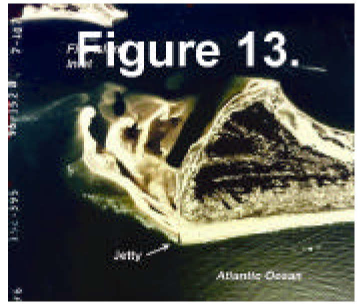
At longer time scales, tectonic movement of an area can alter the conditions for the morphology acting as a control for the shoreline evolution. Tectonic events occur abruptly and typically imply discontinuous changes in the morphological conditions that require adjustment towards new equilibrium situations. In a geological context, the history of tectonic movement is important for defining the type and possible evolution of a coastal area. Thus, classification of coasts has been made based on the tectonics, which provides insight to the expected general behavior of a particular coast. Inman and Nordstrom (1971) distinguished between collision coasts and trailing edge coasts based on the tectonic movement. A collision coast is normally found where the continental plates converge, whereas a trailing edge coast appears where the plates are drifting apart. On collision coasts the continental shelf is narrow with steep offshore slopes and submarine canyons are located close to shore. Deltas and barrier island chains are typically lacking on these coasts, and earthquakes and volcanic activity may influence the coastal evolution. Trailing edge coasts have wide continental shelfs, where substantial deposition of sediments has taken place. Extensive, flat coastal plains are found behind the shoreline, and barrier islands and deltas are common along the coast. A wide continental shelf implies that less wave energy reach the shoreline, the tidal range increases, and deposited sediment on the shelf can act as source for onshore transport. Inman and Nordstrom (1971) also included marginal seacoasts as the third type in their classification scheme. These coasts occur in enclosed or semiprotected seas, for example, the Gulf of Mexico.

Terminal Barrier Islands

Barrier islands typically occur as chains, with tidal inlets separating the individual islands. The most downdrift point in such a system will be subject to significant deposition, and distinct morphological features (spits) often evolve at such points. Factors governing spit evolution have been discussed by

Kraus (1999). Growth of Democratic Point, the westward terminus of a large spit (Figure 12) terminating Fire Island, Long Island, NY, is an example of regional morphologic change with consequences for navigation channel maintenance. If a spit is free to evolve, as is almost the case presently at Fire Island Inlet because of full jetty impoundment, finger spits may evolve, probably associated with major longshore sediment transport occurring during intermittent storms. These finger spits can recurve because of wave action and flood current. Spit growth and recurving can occur intermittently so that the head of the spit consists of finger spits that grow in parallel. Figure 13 shows the finger spits at Fire Island Inlet.





Coastal Projects (Structures, Channels, Large Beach Fills)

Engineering structures and activities influence and are influenced by regional coastal processes. Maintenance dredging for navigation at inlets changes the volume of the flood and ebb-tidal shoals, generating a morphological response that can last over decades (Kraus 2000b; Militello and Kraus 2001). The stabilization of inlets with jetties modifies the tidal prism, which, in turn, changes the equilibrium ebb-tidal shoals (Walton and Adams 1976), forcing the shoals to approach a new equilibrium state. Large beach fills may have length scales close to the regional level, but in many cases coastal projects have spatial dimensions belonging to the local scale.

EXAMPLES OF REGIONAL PROCESSES AND

In the following, a number of examples are given from different locations along the U.S. coast where regional processes and controls to a large degree determine sediment transport,

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channel, and shoreline evolution. Local engineering projects typically have to be considered in the framework of regional processes and controls at such locations. It is also demonstrated that local projects may influence the regional sediment transport pattern, for example, the construction of jetties or the placement of beach fills.

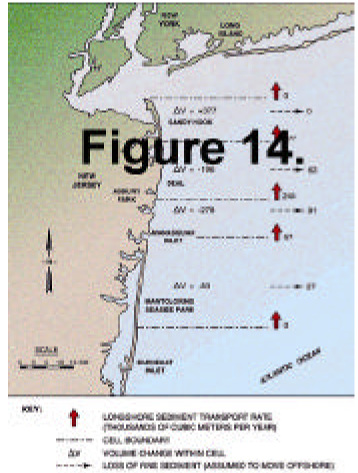
The Long Island Coast

The south shore of Long Island encompasses a variety of geological settings and coastal types, including bluffs, dune systems, headlands, sandy beaches, ponds and bay systems, and barrier beaches with inlets and spits. Rosati, Gravens, and Smith (1999) developed a sediment budget for a 133-km-long stretch of coastline extending from Montauk Point to Fire Island Inlet (see also Taney 1961a, 1961b; Kana 1995). A wide range of coastal processes determines the sediment transport and associated shoreline evolution along this stretch, including processes operating at the regional scale. For example, the alongshore gradients in the long-term wave climate produce a net longshore sediment transport to the west that increases from Montauk Point to Fire Island Inlet, displaying a distinct alongshore regional trend (see Figure 4). Two inlets in the area, Shinnecock and Moriches Inlets, have well-developed ebb-tidal shoals that bypass sediment at present, although the shoals have not yet reached their equilibrium size. Both inlets opened in the 1930s during severe storms, were later stabilized with jetties, and have modified evolution of the shoreline over almost a century as the ebb-tidal shoals evolved.

Several sources of material for the nearshore area exist that have supplied sand over decades. The bluffs at Montauk Point provide a mean sediment input of about 33,000 m^3/year, although the uncertainty is substantial in this estimate (Rosati, Gravens, and Smith 1999). Beach fill and dredged material have regularly been placed along the shore, and adding up all these fills yields an average added sand volume of approximately 300,000 m^3 that is transported towards Fire Island Inlet every year. This transport due to the fill material is comparable with the estimated net annual longshore transport, implying that the fills, typically being local engineering projects, contribute to the regional shoreline evolution and have been necessary for maintaining a stable shoreline. Other regional sources for material to the nearshore are the inner shelf and the shoals found off Fire Island; however, the magnitude of the transport from these sources is still discussed (Rosati, Gravens, and Smith 1999; Schwab et al. 1999). Sea-level rise and wind-blown sand also influence the long-term shoreline evolution at Long Island, but these processes have typically been assumed to yield a small contribution in previous studies.

The New Jersey Coast

Caldwell (1966) summarized a regional sediment budget developed in the 1950s by the Corps for the north New Jersey coast (U.S. Congress 1957, 1958). The budget was formulated by analyzing differences in shoreline position with the objective of examining alternatives to mitigate for erosion over a wide stretch of urbanized and semiurbanized beach. This study deduced a regional divergent nodal point in net longshore transport direction at Mantoloking, located just north of Dover Township, which is still considered valid. Net longshore transport to the north increased with distance north from Mantoloking because of the wave sheltering by Long Island, NY (that is, waves coming from the south become more dominant). The budget covered average annual net and gross longshore sand transport rates for this 190-km reach including 10 inlets over time intervals of 50 to 115 years. Both the magnitudes and directions of transport found are still considered to be valid (Figure 14).



The Georgia and Florida Coast

Byrnes and Hiland (1995) deduced the regional sediment transport pattern on the continental shelf seaward of Cumberland Island, GA, and Amelia Island, FL, by analysis of georeferenced historical shoreline positions and bathymetric maps. The study area was bounded by two inlets (St. Andrew Sound to the north and Nassau Sound to the south) with the two barrier islands separated by St. Mary's Entrance. Jetty construction at this entrance in the late 1800s caused significant spatial variability in the net rate of shoreline change. The introduction of the jetties, in combination with channel dredging, markedly increased the ebb-tidal shoal (Olsen 1977; Knowles and Gorman 1991). Shoreline advance was documented along most stretches of the islands, although shoreline retreat was recorded along the southernmost part of Amelia Islands since the end of the 1800s. It was concluded that most of the shoreline change occurring in the area was associated with the three tidal inlet systems. A sediment budget for the area demonstrated that processes determining littoral zone sand transport had minimal influence on regional change; however, the shoreline response was a function of the shelf sediment flux.

The California Coast

California has 2,900 km of ocean coastline, with 1,100 km of sandy beaches and a number of estuaries and coastal lagoons. Most of the sediment brought to the shoreline is from the coastal streams and rivers, which derive their sediment from drainage basins. Their sediment yield is related to the effective precipitation in the drainage basin and the area of the drainage basin. Sea cliff erosion, gully erosion, onshore transport of sand from shallow water, and introduction of biogenous material produced by plants and animals may also contribute to the littoral budget (Inman 1976; Best and Griggs 1991). Sediment transport processes along the California coast can be segregated by littoral cells, which are segments of the coastline that encompass a complete cycle of sediment supply, transport, and loss (Bowen and Inman 1966; Inman and Frautschy 1966). In most cases, a littoral cell receives sediment from rivers and streams, which is then transported by wave action in the alongshore or cross-shore direction. Transport continues until it is intercepted by a submarine canyon, harbor, inlet, or other sink. In certain regions, wind-blown sand that subsequently forms dunes can be a source or a sink to the littoral system

(Best and Griggs 1991). Griggs (1987) noted that marinas and harbors constructed at the ends of or between littoral cells are, in general, maintenance free, whereas those constructed in the middle portion of littoral cells have significant dredging requirements.

In a sediment budget for the Santa Cruz littoral cell, which extends from the entrance to San Francisco Bay in the north to Santa Cruz Harbor in the south, Best and Griggs (1991) estimated that 75 percent of the sediment source is due to coastal streams, and 20 percent is due to bluff erosion. In the sediment budget analysis, Best and Griggs calculated that sources to the system only account for 24 to 57 percent of the longshore transport at the southern cell boundary. They present three reasons for this possible discrepancy: (a) incorrect location of the northern cell boundary, (b) reduced deposition to the beaches or inner shelf (difficult to estimate due to lack of long-term beach surveys), or (c) episodic input of sediment to the system from streams due to storms that couldn't be accounted for due to the time period of the data base (only two of the 13 streams and creeks monitored had over 1 year of data). This study highlights how information about long-term, regional-scale processes is necessary to accurately represent present day behavior of the coastal system.

CONCLUSIONS

Although the navigation mission of the Corps typically concerns the design, construction, and maintenance of projects on a local scale, the influence of these projects may extend to the regional system over longer time scales. As opposed to individual homeowners, county and state governments, and other Federal agencies, the Corps' role spans both political and geographic boundaries, and as such, must consider regional implications. Because Federal projects can continue for decades to centuries, and navigation channels are modified to accommodate larger vessels, the potential for a local project to change the regional waves, currents, and sediment transport patterns increases. This CHETN introduced various regional coastal processes and controls that may be significant to the design and maintenance of a local project.

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ADDITIONAL INFORMATION

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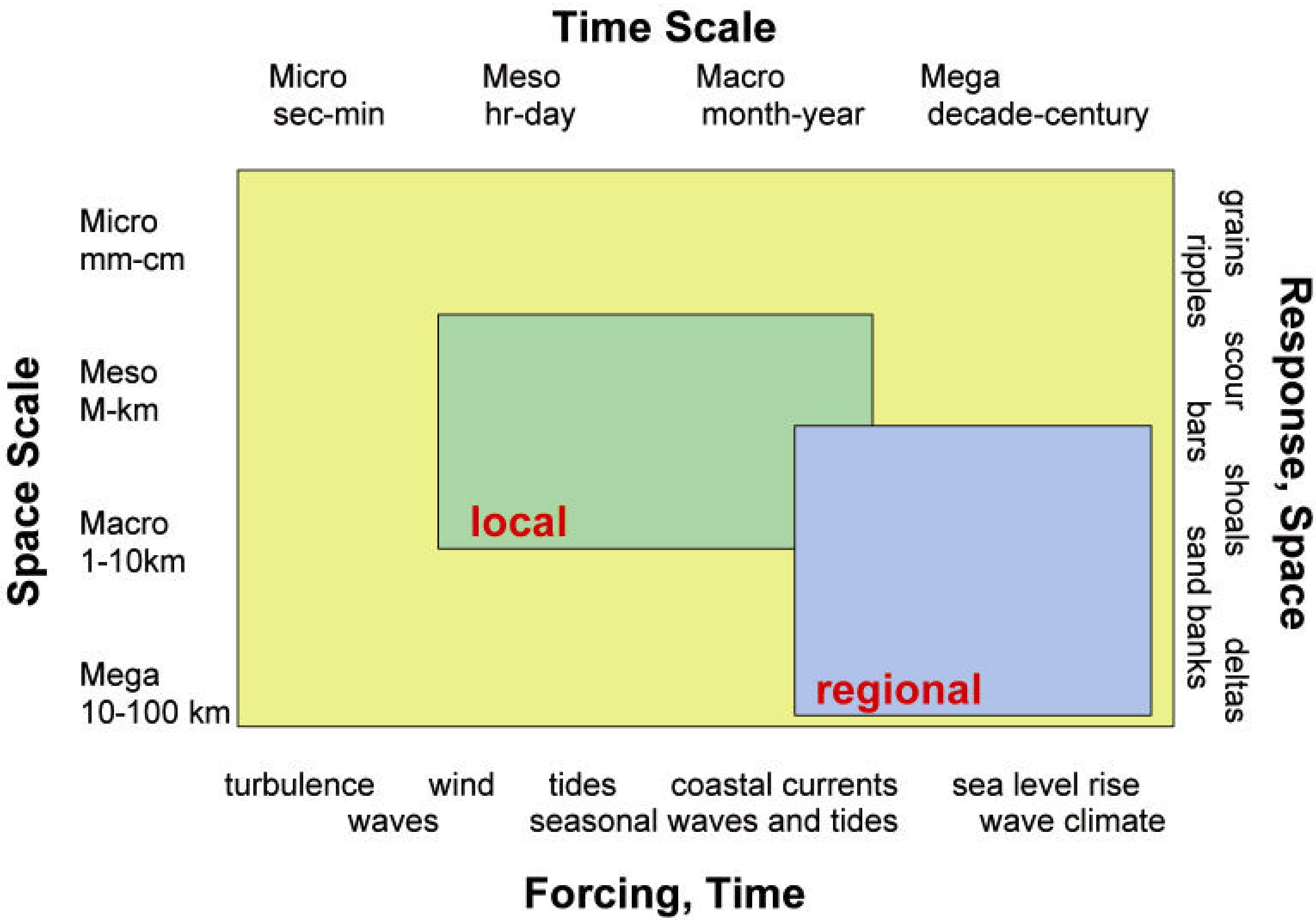

Figure 1. Classification of coastal processes with respect to time and space scales (adapted from Larson and Kraus 1995)

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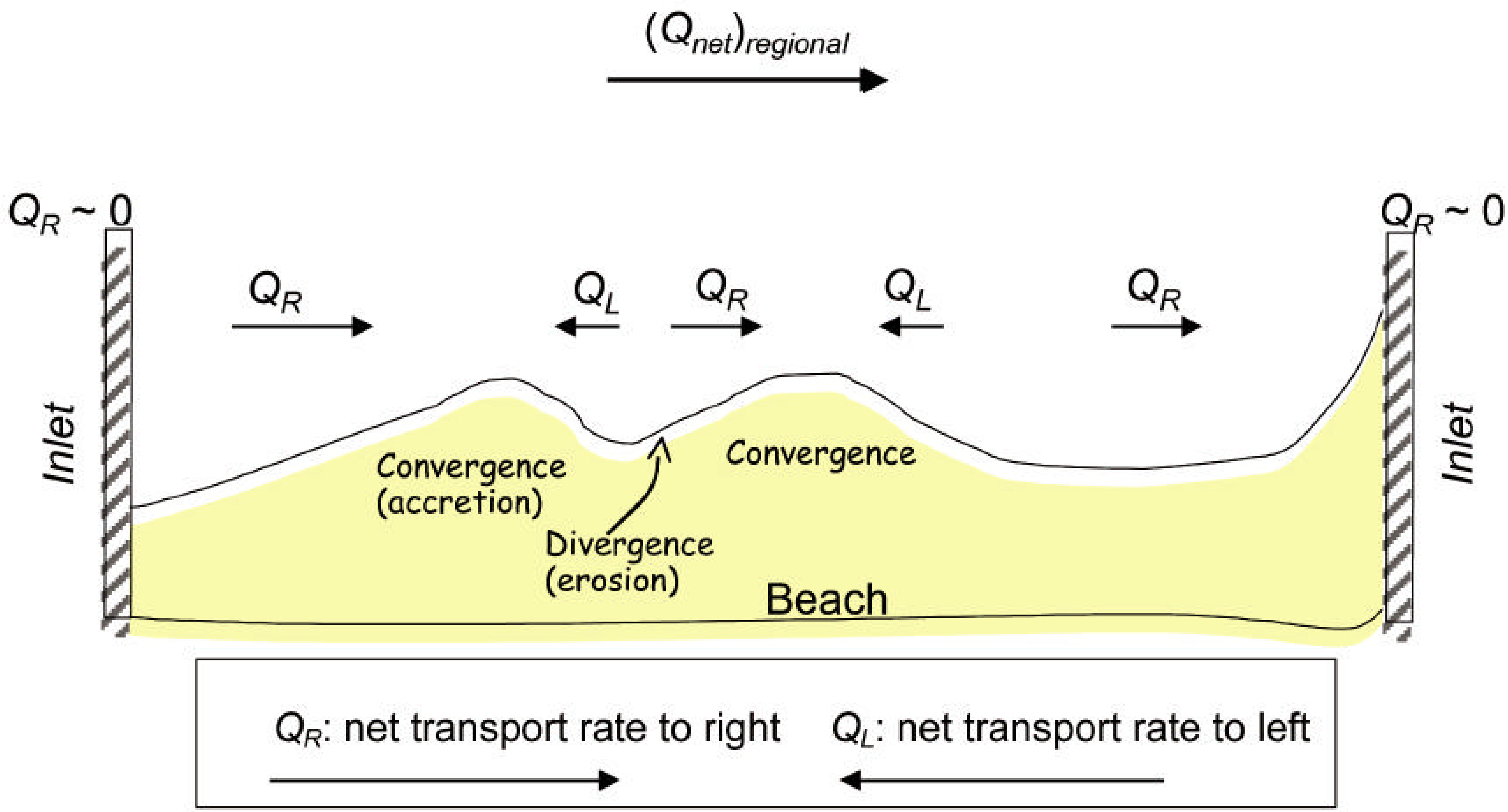

Figure 2. Gradients in the local longshore transport causing areas of erosion and accretion

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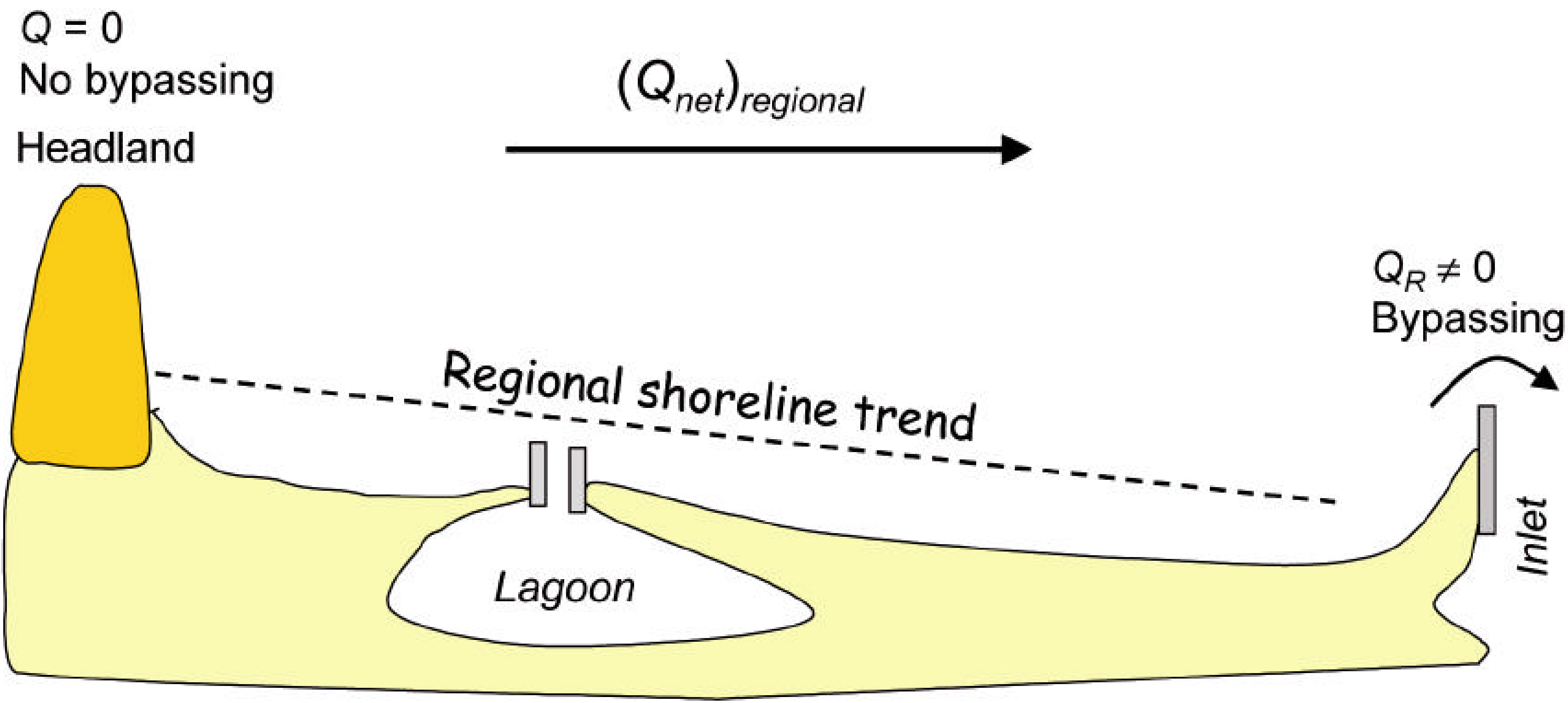

Figure 3. Regional trend in shoreline created by blockage of sand by large headland

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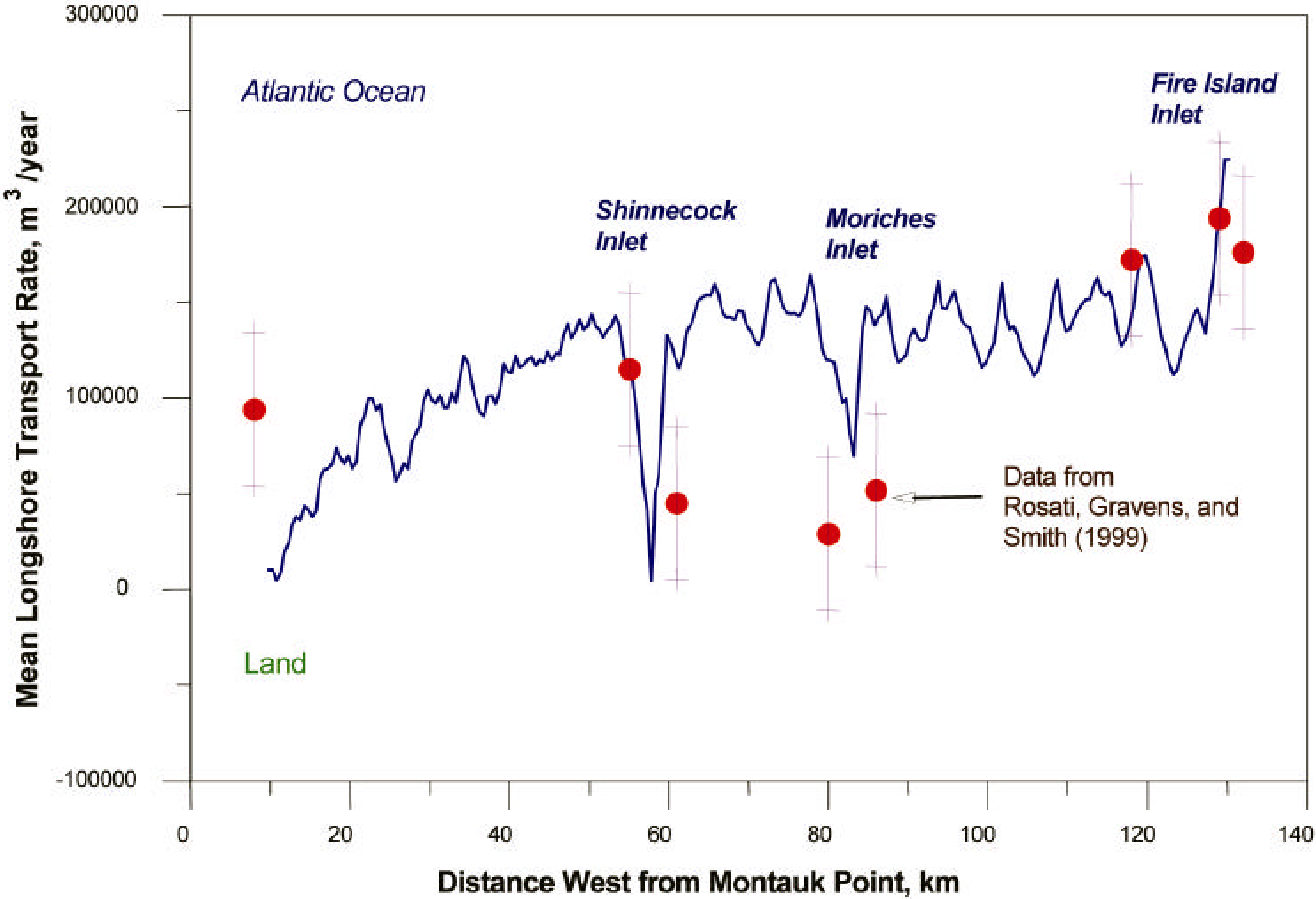

Figure 4. Calculated regional trend in the annual net longshore sand transport along the south shore of Long Island, New York (the horizontal axis goes from east to west)

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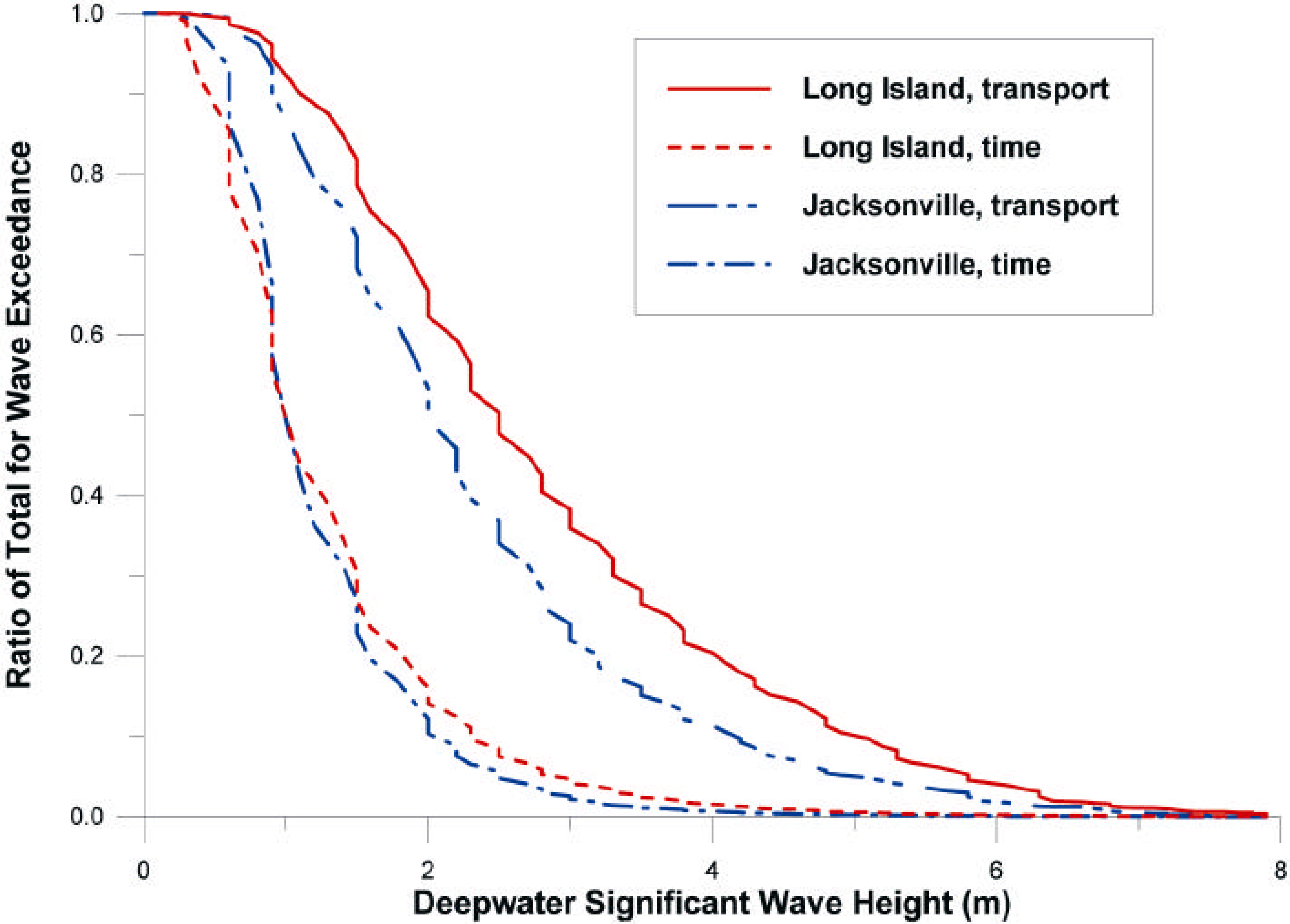

Figure. 5. Ratios of total gross longshore sand transport rate and duration of wave action exceeding a specific wave height for Long Island, NY, and Jacksonville, FL

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Figure 6. Ocean City Beach on lower right (north), and Assateague Island, MD, on the upper left (August 1979)

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Figure 7. Washover fans on Assateague Island, MD

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Figure 8. Coastal bluffs at Torrey Pines, CA, April 2001 (photograph courtesy Ms. Kiki Runyan)

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Figure 9. Alongshore sand waves at Southampton Beach, Long Island

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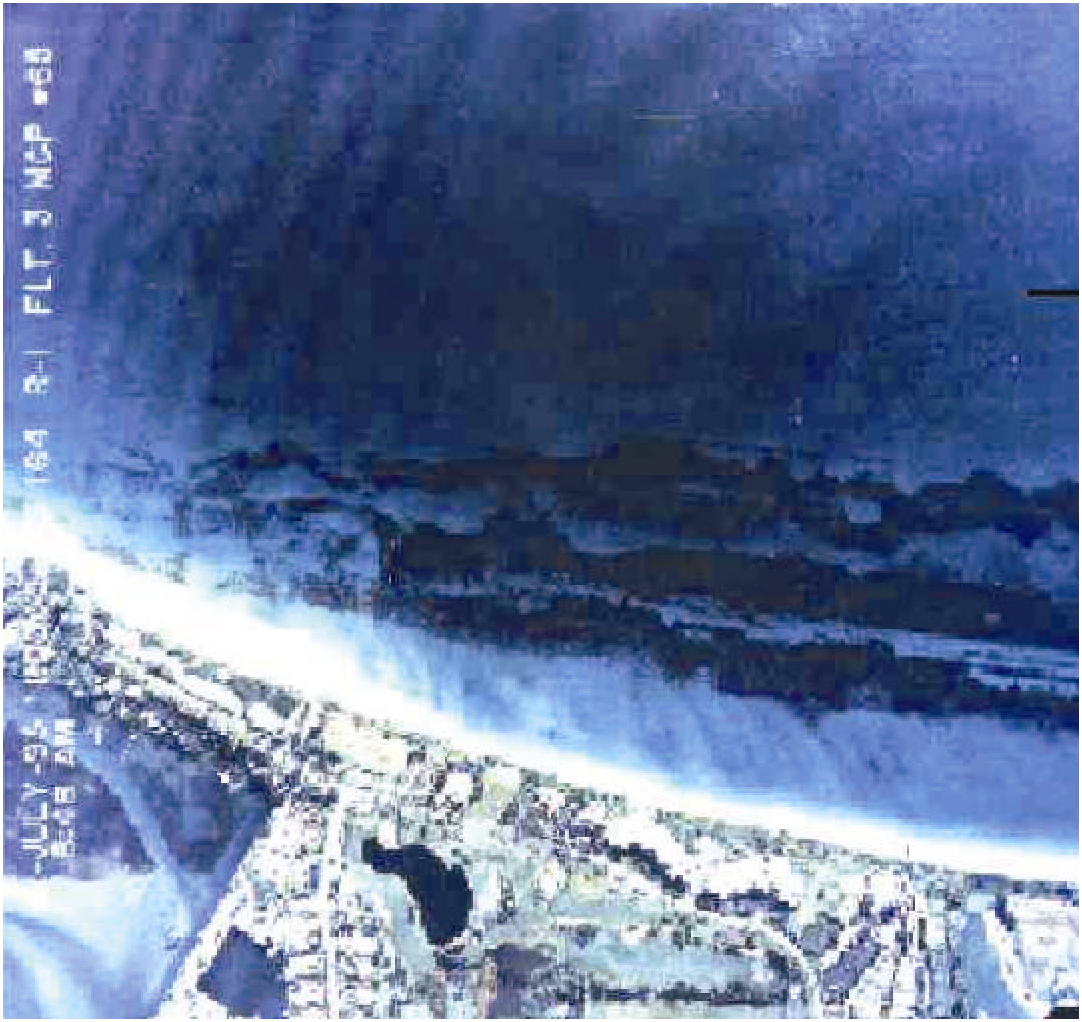

Figure 10. The nearshore at Martin County Beach Park at Bathtub Reef showing three bands of hard bottom (from Larson and Kraus 2000)

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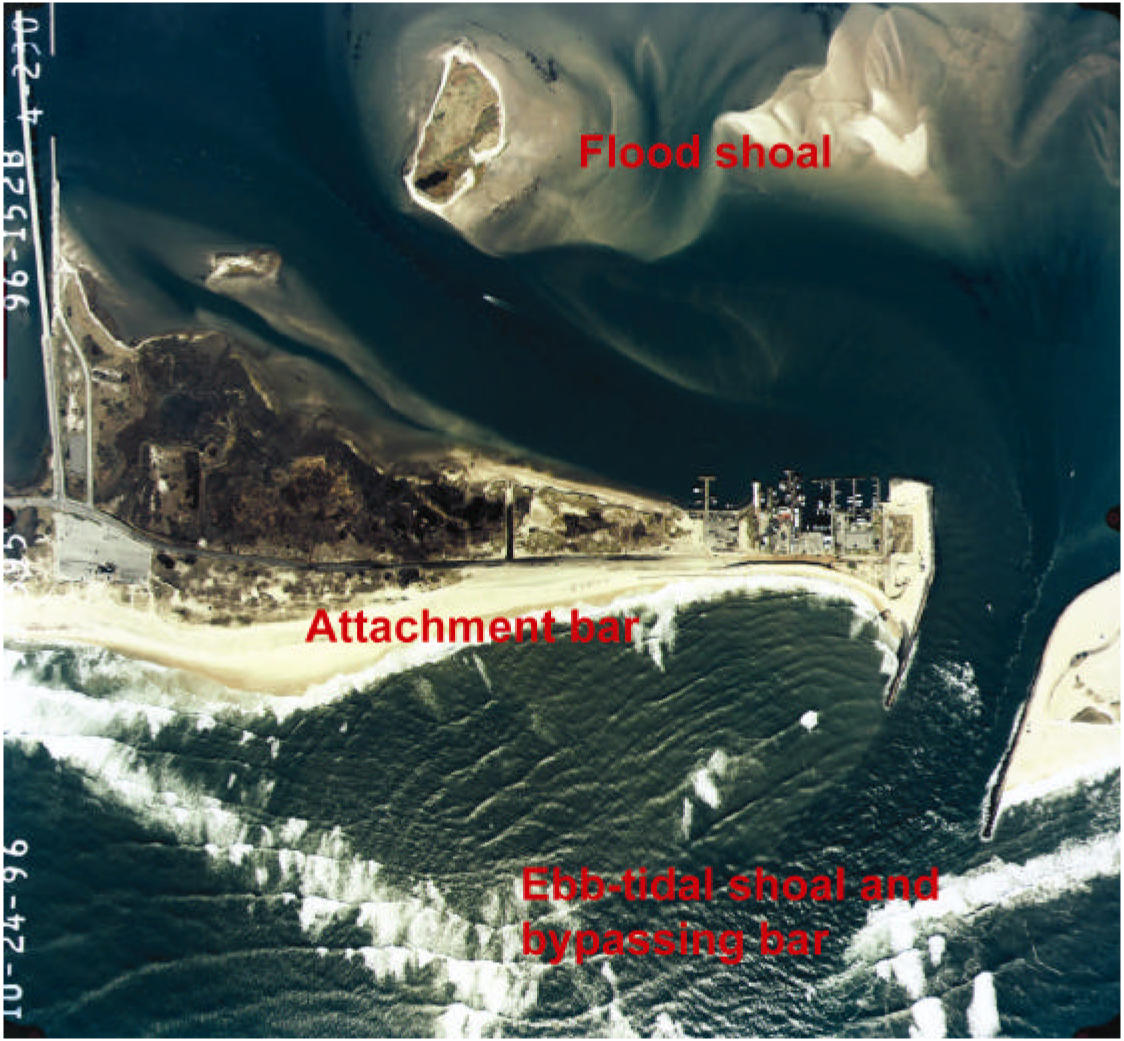

Figure 11.   Shinnecock Inlet, Long Island, illustrating the major morphological elements of the inlet

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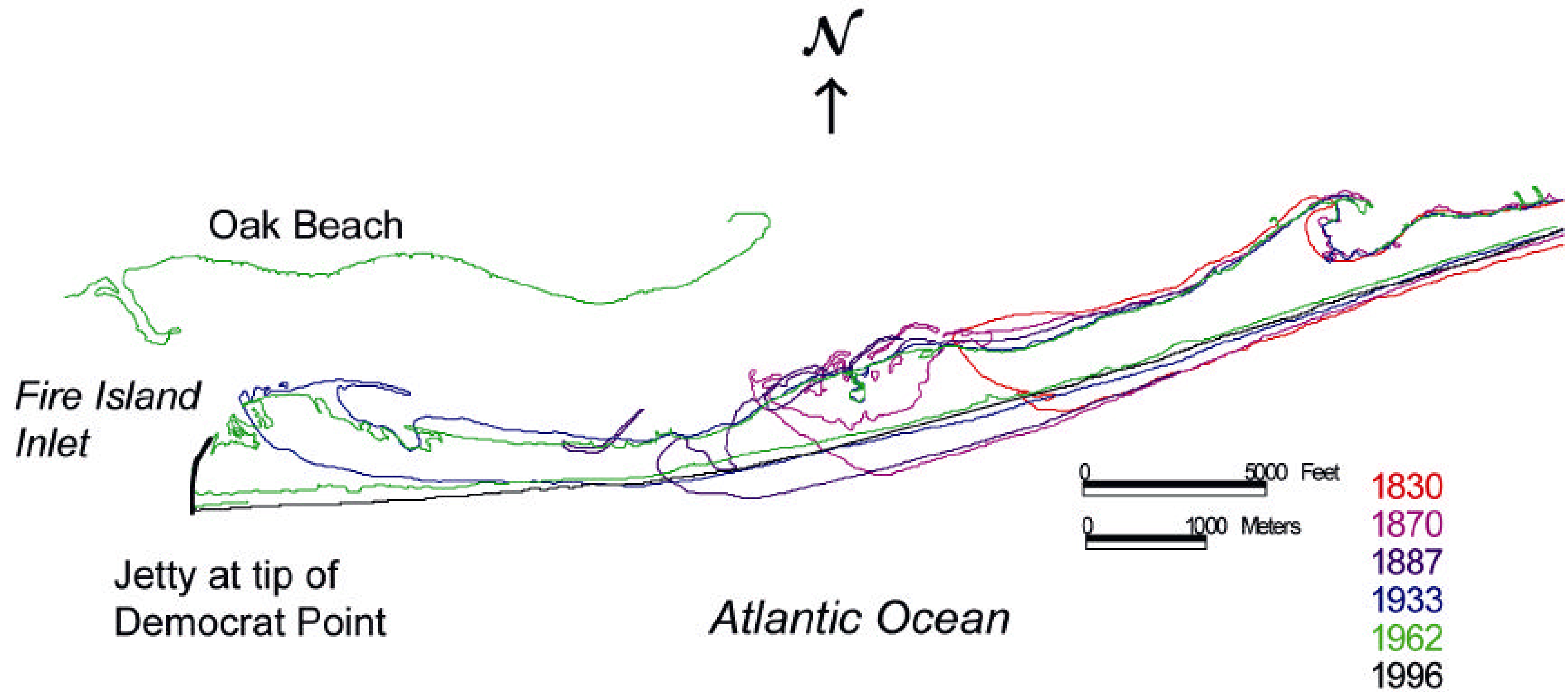

Figure 12. Growth of Fire Island, Long Island, NY

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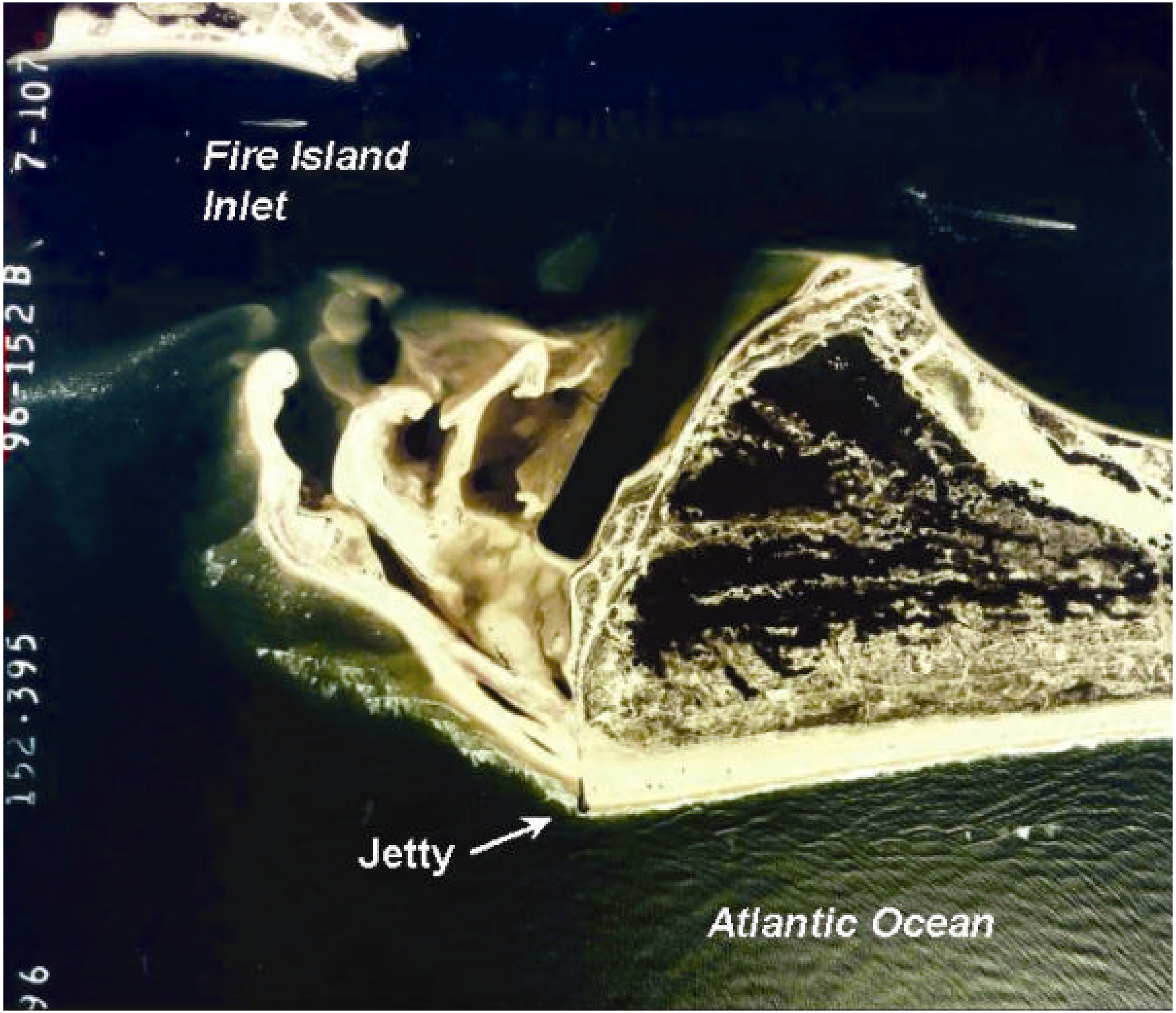

Figure 13. Recurved finger spits, Fire Island Inlet, Long Island, NY

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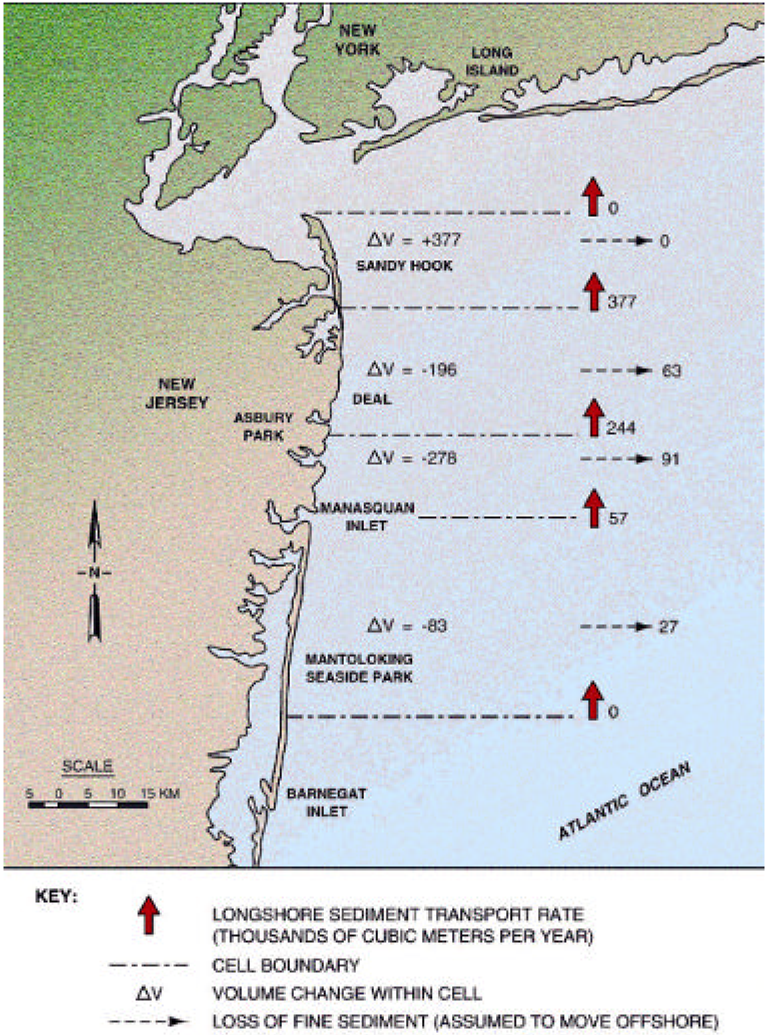

Figure 14. Sediment budget for north New Jersey (adapted from Caldwell 1966)

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